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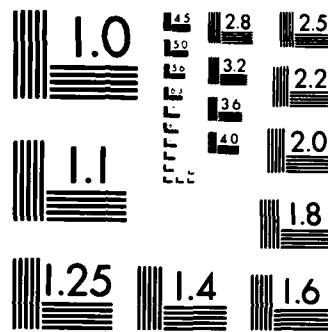
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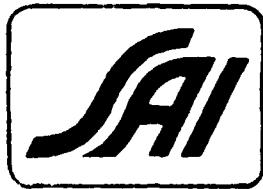
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**SAI INTERIM SCATTERING MODEL/ICE (SISM/ICE)**

**SAI-84/1100**

**April 1984**

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## SAI INTERIM SCATTERING MODEL/ICE (SISM/ICE)

The SAI Interim Scattering Model/Ice (SISM/ICE) is a reflection loss model for the coherent reflected field in ice-covered environments. The standard deviation of roughness is the only parameter required by the model for predictions. A contour map of the standard deviation of roughness in meters, shown in Figure 1, is from Buck.<sup>1</sup> It is already available to Fleet users as part of Buck's empirical transmission-loss model. The range of validity of SISM/ICE is from 0-5000 Hz and 0-45 degrees. A sequence of scattering-loss formulas based on perturbation techniques provides a smooth transition in frequency to an asymptotic loss level at the highest frequencies. The perturbation formulas are derived in Bass and Fuks<sup>2</sup> and are summarized in Stokes.<sup>3</sup> The derivation of the formula for the asymptotic loss level is contained in Burke and Twersky<sup>4</sup> and is the same one used in Diachok.<sup>5</sup> In addition, probabilistic techniques derived by R. Greene are used to relate the standard deviation of roughness to the ice-roughness parameters required by the individual reflection-loss formulas.

### Ice Roughness Parameters

The under-ice surface is considered to be flat with cylindrical bosses of elliptical cross section.

The bosses:

- 1) have a half-width-to-depth ratio of 1.6, as suggested by Diachok,<sup>5</sup>
- 2) have a Rayleigh depth distribution,

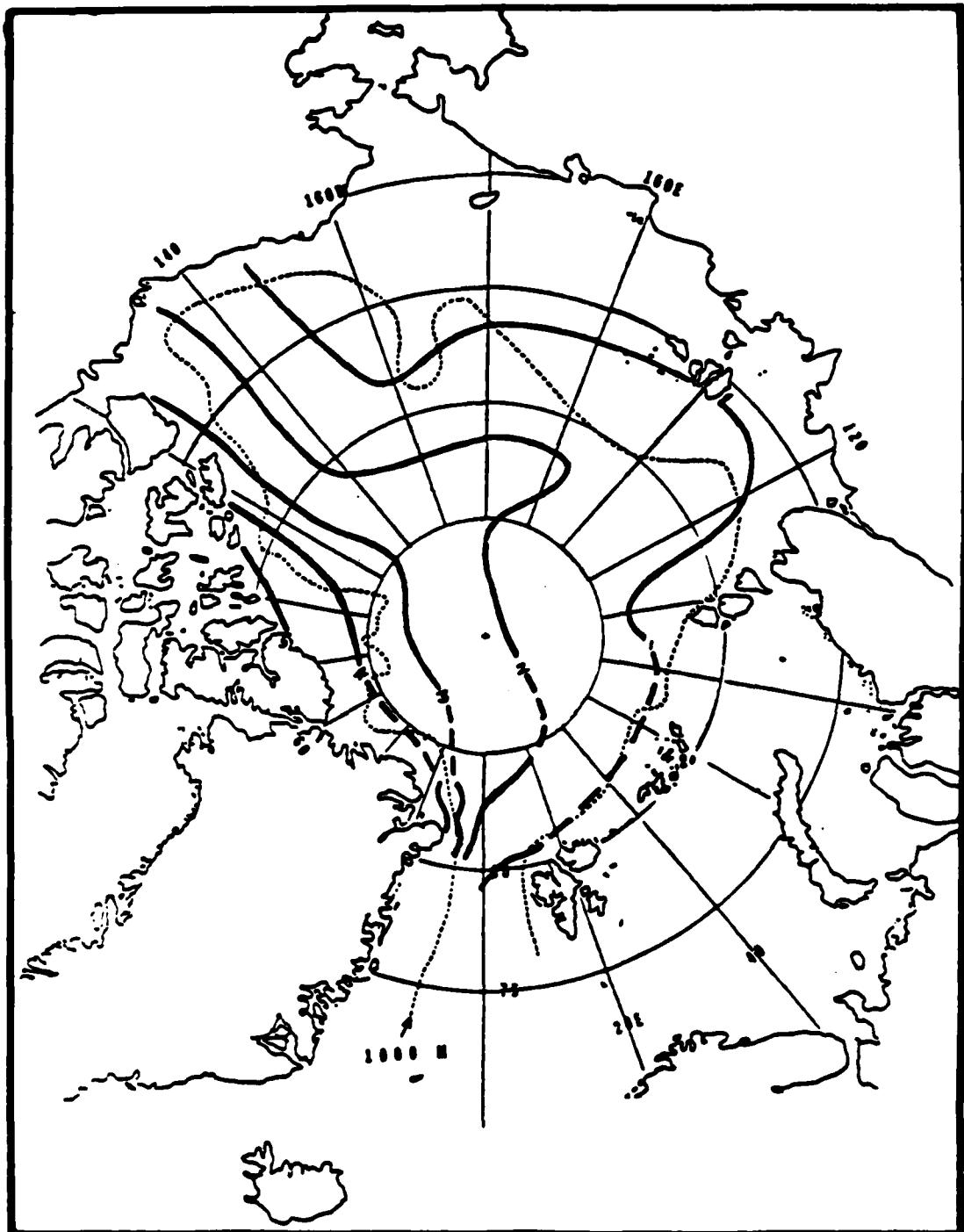


Figure 1. Contours of standard deviation ice depth (m) per LeSchack (Ref. 1 & 2). Dotted line (...) is 1000 m depth contour.

- 3) have random orientation,
- 4) have random spacing along a track.

Based on these assumptions, the standard deviation of roughness is related to the ridge keel parameters by the formula:

$$\sigma^2 = \frac{4 R_0 h^3}{\Delta} - \frac{\pi^2 R_0^2 h^4}{\Delta^2}, \quad (1)$$

where:

$\sigma$  is the standard deviation of roughness,  
 $R_0 = 1.6$  is the half-width-to-depth ratio,  
 $\Delta$  is the mean keel spacing, and  
 $h$  is the mean keel depth.

Under-ice roughness spectra measured along a track can be well approximated by the function:

$$\frac{c}{(\beta^2 + K^2)^{3/2}}, \quad (2)$$

where  $K$  ( $=2\pi/\lambda$ ) is the wave number of the roughness component in the surface. This function has an asymptotic fall-off for large  $K$  of the form:

$$\frac{c}{K^3}. \quad (3)$$

The standard deviation of roughness derived from such a spectrum is:

$$\sigma^2 = \frac{2c}{\beta^2}. \quad (4)$$

The roughness spectrum derived from the bossed surface has the same asymptotic behavior as Eq. (3), where the coefficient  $c$  can be calculated to be:

$$c = \frac{\pi h}{8\Delta R_0} . \quad (5)$$

Derivation of Ice-Roughness Parameters from Standard Deviation Roughness

It is assumed that of all the ridge parameters, the mean spacing is the most slowly varying as a function of the standard deviation of roughness. It is assigned a constant representative value of 100 meters:

$$\Delta = 100 \text{ m} . \quad (6a)$$

The mean ridge-keel depth ( $h$ ) in meters, can be found as the solution of Eq. (1) by the iteration:

$$h_{n+1} = [(\Delta/4R_0)(\sigma^2 + \pi^2 R_0^2 h_n^4/\Delta^2)]^{1/3} , \quad (6b)$$

where:

$$R_0 = 1.6 . \quad (6c)$$

The asymptotic coefficient ( $c$ ), of the spectral model, Eq. (2), is calculated using Eq. (5):

$$c = \pi h / 8\Delta R_0 \quad (6d)$$

The  $\beta$  coefficient of the spectral model is calculated using Eq. (4):

$$\beta = (2c/\sigma^2)^{1/2} . \quad (6e)$$

### Reflection-Loss Formulas

In terms of the ice-roughness parameters, four formulas for the reflected power  $|R^2|$  are evaluated. The predicted value of  $|R^2|$  is the maximum of the four calculated values.

Choose the maximum of:

- Low Frequency-Free Surface Formula

$$|R|^2 = 1 - 4 \sin\theta k^2 \sigma^2 (1 - \pi^2 c (\sin\theta)/2) , \quad (7a)$$

- High Frequency-Free Surface Formula

$$|R|^2 = 1 - 4 \sin\theta (1.198) c (k/\beta)^{3/2} , \quad (7b)$$

- High Frequency-Rigid Surface Formula

$$|R|^2 = \begin{cases} \frac{(\sin\theta - x)^2 + x^2}{(\sin\theta + x)^2 + x^2} , & x < \sin\theta , \\ .2 & , x > \sin\theta , \end{cases} \quad (7c)$$

where:

$$x = 1.311 c (k/\beta)^{1/2} .$$

- Asymptotic Twersky formula

$$|R|^2 = (\sin\theta - x)^2 / (\sin\theta + x)^2 , \quad (7d)$$

where:

$$\begin{aligned}x &= n L \cos(\theta - \gamma), \\ \tan\gamma &= \rho^{-2} \tan\theta, \\ L^2 &= w^2(\tan^2 \theta + \rho^4)/(\tan^2 \theta + \rho^2), \\ w &= R_0 \pi h/2, \\ \rho &= 2/(R_0 \pi), \\ n &= 1/\Delta.\end{aligned}$$

In all of formulas 7a-7d,  $\theta$  is grazing angle and  $k$  is the acoustic wavenumber in inverse meters.

### Conclusion

SISM/ICE is suggested as an interim scattering-loss model in ice-covered environments. It is based on several simplifications and assumptions. However it fulfills the requirement for a loss model with a wide range of validity, based on the only known environmental parameter, the standard deviation of roughness. SISM/ICE can be used with acoustic propagation models such as FACT and RAYMODE to predict the coherent propagating field. There may also be a significant propagating incoherent component at the higher frequencies, which would not be predicted by these models. As propagation models become available which can describe the propagating incoherent field, SISM/ICE can be extended to give the scattering kernel for the incoherent field. The details for doing this are contained in Refs. 2, 3, and 4.

## REFERENCES

1. B. M. Buck, "Preliminary Underice Propagation Models Based on Synoptic Ice Roughness (Area TR No. 9)," Polar Research Laboratory Report TR-30, 123 Santa Barbara St., Santa Barbara, CA 93101 (May 1981).
2. F. G. Bass and I. M. Fuks, Wave Scattering from Statistically Rough Surfaces, Pergamon Press, New York (1979).
3. A. P. Stokes, "A Primer on Rough Surface Scattering," Science Applications Inc. Report No. SAI-83-140-WA, 1710 Goodridge Drive, McLean, VA 22102 (April 1983).
4. J. E. Burke and V. Twersky, "Scattering and Reflection by Elliptically Striated Surfaces," J. Acoust. Soc. Am. 40, 883-895 (1966).
5. O. I. Diachok, "Effects of Sea-Ice Ridges on Sound Propagation in the Arctic Ocean," J. Acoust. Soc. Am. 59, 1110-1120 (1976).

## Appendix

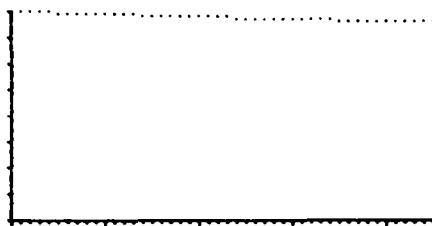
### REFLECTION LOSS CURVES FOR REPRESENTATIVE ARCTIC ENVIRONMENTS USING SISM/ICE

The curves are evaluated for: Standard Deviation of Roughness, sigma = 2 m and 4 m, and frequencies (Hz), Freq = 20, 50, 100, 200, 800, 3500, 5000.

- The vertical scale represents the power reflection coefficient,  $R^2$ . The scale goes from .2 to 1.0 in units of .1.
- The horizontal scale represents grazing angle in degrees. The scale goes from 0 to  $45^\circ$  by degree.

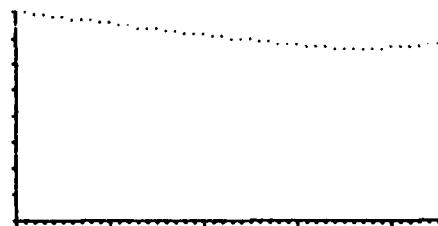
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R<sup>2</sup>= .2 TO 1.0



FREQ =50  
SIGMA=2

R<sup>2</sup>= .2 TO 1.0

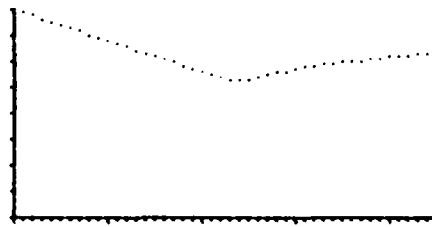


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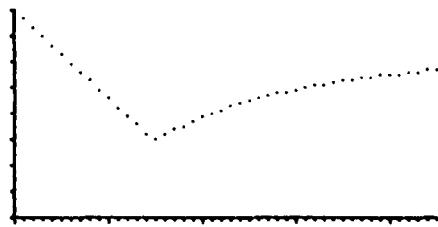
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R<sup>2</sup>= .2 TO 1.0



FREQ =200  
SIGMA=2

R<sup>2</sup>= .2 TO 1.0

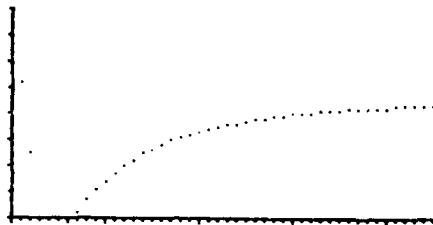


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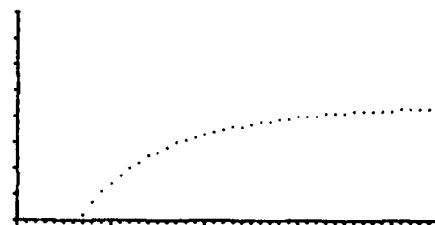
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R<sup>2</sup>= .2 TO 1.0



FREQ =3500  
SIGMA=2

R<sup>2</sup>= .2 TO 1.0

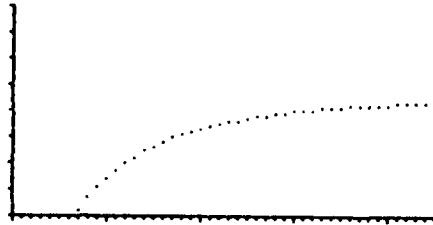


ANGLE = 0 TO 45°

ANGLE = 0 TO 45°

FREQ =5000  
SIGMA=2

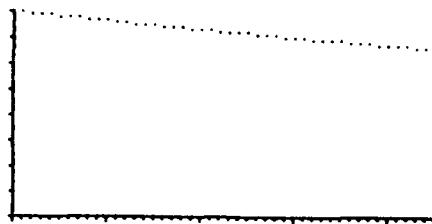
R<sup>2</sup>= .2 TO 1.0



ANGLE = 0 TO 45°

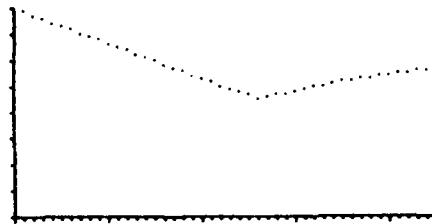
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R<sup>2</sup>= .2 TO 1.0



FREQ =50  
SIGMA=4

R<sup>2</sup>= .2 TO 1.0

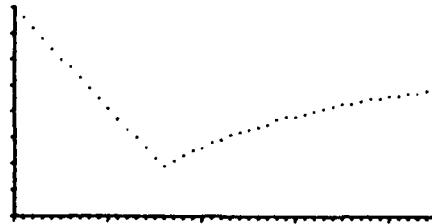


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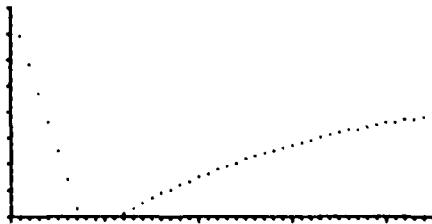
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R<sup>2</sup>= .2 TO 1.0



FREQ =200  
SIGMA=4

R<sup>2</sup>= .2 TO 1.0

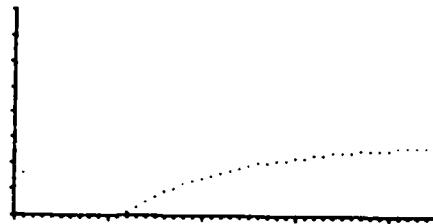


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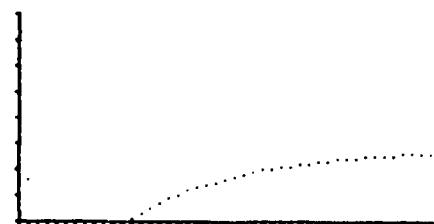
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R<sup>2</sup>= .2 TO 1.0



FREQ =3500  
SIGMA=4

R<sup>2</sup>= .2 TO 1.0

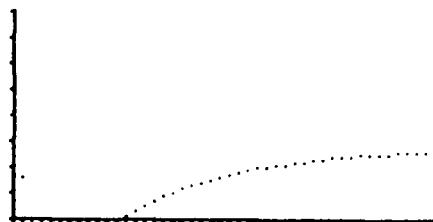


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ANGLE = 0 TO 45°

FREQ =5000  
SIGMA=4

R<sup>2</sup>= .2 TO 1.0



ANGLE = 0 TO 45°

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